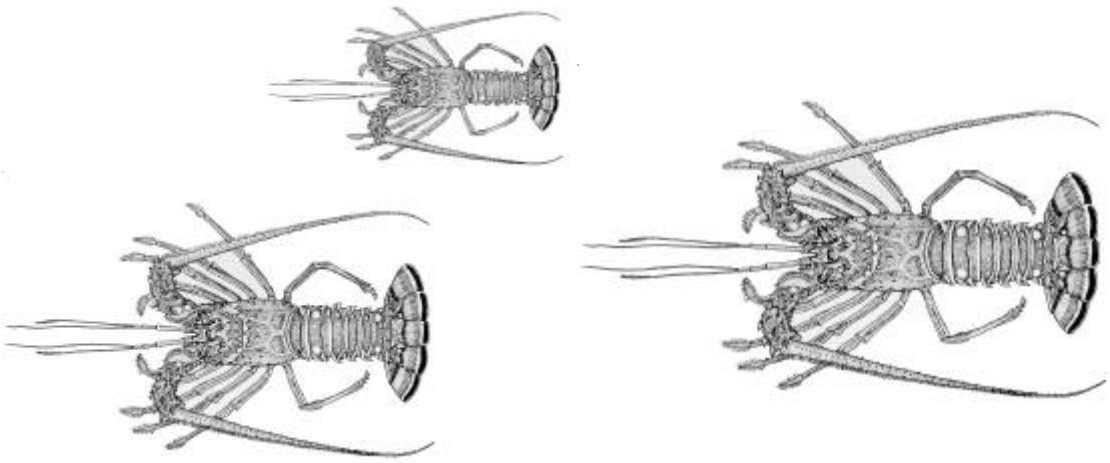

The 2000 update of the stock assessment for spiny lobster, *Panulirus argus*, in the Florida Keys

by

Robert G. Muller[1], William C. Sharp[2], Thomas R. Matthews[2], Rod Bertelsen[2], and John H. Hunt[2]

Fish and Wildlife Conservation Commission
Florida Marine Research Institute
[1] 100 Eighth Avenue, Southeast
St. Petersburg, FL 33701-5095
[2] 2796 Overseas Highway, Suite 119
Marathon, FL 33050

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EXECUTIVE SUMMARY

Commercial and recreational landings were updated through the 1999-2000 fishing season. Landings were combined with lengths and sexes to estimate the number of lobsters landed by ages and season. In turn, catch-at-age data were analyzed together with indices of abundance using the same age-structured, separable virtual population method that was used in previous assessments to estimate population sizes, fishing mortality rates, and recruitment trends. In addition, we applied Prager's non-equilibrium, surplus-production model (ASPIC) to total landings and trips to estimate the historical biomass trajectory, ratio of current biomass to the biomass that produces maximum sustainable yield (MSY), and the ratio of current fishing mortality to that at MSY.

Commercial landings from this past season were 6.3 million pounds, up from last season's 4.9 million pounds. Historical landings by calendar year from 1950 through 1999 show that landings after the Trap Reduction program began have been high except for the 1998-99 season.

The estimated recreational harvest in July and August 1999 in the Florida Keys was 1,190,000 lobsters which was higher than last season's harvest of 837,000 lobsters which was the lowest harvest since August 1992 when Hurricane Andrew passed through southern Florida.

Three indices of abundance indices were to tune the age-structured analyses: 1) the seasonal average pounds per commercial trip adjusted for month, number of traps, soak time and trip duration; 2) the seasonal average pounds per trap from the observer program adjusted for soak time, month, and zone; and 3) an age specific index of the number of lobsters (68-75 mm carapace length) per trap that are expected to enter the fishery during a particular season. For males, these pre-recruitment lobsters were considered as being age-one, i.e. between their first and second year and for females these lobsters were considered as age-two.

Using the same natural mortality rate of 0.34 per year that was used in previous assessments, the population of lobsters that comprise most of the fishery (ages two through seven) has been stable for both sexes since the 1994-95 season. Age-two continues to be the modal age in the landings. The fishing mortality rates in 1999-00 for fully recruited ages (F = 0.37 per year for females and 0.49 per year for males) were higher than last season and back to more typical levels.

The surplus-production model, ASPIC, supported the findings from the age-structured model that fishing mortality in 1998-99 was down and that biomass had fluctuated in a manner similar to that estimated with the age-structured model (correlation coefficient = 0.80, *d.f.* = 11, $P < 0.05$) with higher values in recent years. Based upon 1,000 simulation iterations, the median ratio of current biomass to the biomass at MSY was 0.81 (121 outcomes were 1.00 or greater) and the median ratio of current fishing mortality to fishing mortality at MSY was 1.02 (422 outcomes were less than 1.00).

The transitional spawning potential ratios based upon biomass have varied from 23% to 29% with the value at the end of the 1999-00 season being 28%. When transitional spawning potential ratios were calculated using the number of eggs instead of biomass, the values were higher 4% higher, i.e. ranging from 27% to 33% with the value at the end of the 1999-00 season being 32%.

In summary, the lobster fishery continues fluctuate without trend as it has done for 30 years. Landings from both sectors were up this season after being down in the 1998-99 season. The evidence indicates that lobster biomass in the Florida Keys is increasing although the overall average fishing mortality rates after the Trap Reduction Program have been similar to those from before the program. A possible explanation for the increase in the fishable population stems from the fishery using fewer sub-legal lobsters to bait the remaining traps.

INTRODUCTION

Spiny lobsters, *Panulirus argus*, have been commercially fished in the Florida Keys for over 100 years (Labisky *et al.* 1980). In 1999, the fishery for spiny lobster statewide was Florida's most valuable fishery with an ex-vessel value of $31.9 million which exceeding pink shrimp's ex-vessel value of $25.9 million (Fish and Wildlife Conservation Commission (FWC), Marine Fisheries Information System, unpublished data). Recreational divers also target spiny lobsters during the regular season which begins on August 6 each year as well as during the two-day Special Sport Season in late July. When the State of Florida Legislature reduced the minimum size to 3 inches (76.2 mm) in 1965, fishers were able to expand their fishing area for spiny lobster into Florida Bay and, after an brief adjustment period, lobster landings from the Florida Keys have varied without trend since 1970. Recent landings, except for 1998-99, were among the highest on record.

Prior to the age-structured assessment by Muller et al. (1997), the condition of Florida's spiny lobster fishery and the ramifications of alternative management measures were assessed with Ricker yield-per-recruit models (Ricker 1975, Powers and Thompson 1986, Powers and Sutherland 1989). This assessment follows the more data-intensive methods in Muller et al. (1997) with the addition of a non-equilibrium, surplus-production model (Prager 1994).

METHODS

We extracted all commercial spiny lobster records that were received by the FWC's Fishery Dependent Monitoring Group through 24 July 2000 from Florida's Marine Fisheries Information System, commonly known as the Trip Ticket System. Records through Batch 601 had completed the editing process while records from Batch 602 through Batch 621 were only partially edited. This assessment focuses on the spiny lobster fishery in the Florida Keys and we analyzed only those records from the period July 1987 through March 2000 that specified Monroe county as the county of landing. Commercial landings for the 1999-00 fishing season were considered as preliminary and the landings for 1998-99 season were updated in this assessment because additional trip tickets were received after last year's update.

Recreational landings have been estimated for the two-day sport season in late July and for the period between August 6 and Labor Day (the first Monday of September) with mail surveys of recreational lobster license holders since 1991 (Sharp et al. In press). A survey of the 1994-95 fishing season after Labor Day conducted by FMRI showed that the recreational landings made after Labor Day were quite low compared to the amount landed earlier in the season. We are

assuming that this seasonal pattern has not changed significantly for other fishing seasons covered in this analysis. Recreational landings prior to 1991 were extrapolated using a regression of the 1991 through 1999 recreational landings on commercial landings.

Two types of programs measure the sizes of lobsters captured in the Keys' commercial fishery: fish house sampling and on-board observers. The National Marine Fisheries Service's sampler in Key West has measured and recorded the sex of lobsters at fish houses in the lower Keys since August 1986 and FWC samplers have measured and recorded the sex of spiny lobsters throughout the Keys since August 1987. Carapace lengths (CL) are recorded to the nearest 1 mm. Since 1993, observers onboard commercial lobster vessels have identified and measured the total catch brought up in traps. This additional information is crucial because traps capture lobsters smaller than legal size and lobsters down to about 50 mm carapace length (CL) are subjected to additional mortality when placed in traps as live attractants (see Heatwole et al. 1988).

To avoid masking underlying patterns, we partitioned landings and lengths into geographic zone, time period within a fishing season, and sex. For commercial landings, we divided the Florida Keys into two zones based upon differences in the fishery. The Upper Keys zone extended from Key Largo to West Summerland Key and the Lower Keys zone extended from Big Pine Key to Key West. This year instead of using the location of the fish house to assign landings to either the Upper or Lower Keys, we used the area-fished field on each trip ticket and the fish house location if the area information was missing. Originally, the area fished field was voluntary but has been required since 1994 so now there are several years with area-fished information. The location of observer size information was used directly. The periods within a fishing season were Summer (July to October), Winter (November to January), and Spring (February and March) .

Commercial landings are reported in pounds (lobsters landed as tails were converted to body weight with a factor of 3.0 times tail weight) and pounds must be converted into numbers of lobsters per stratum before the commercial landings can be combined with the recreational landings for subsequent analysis. Sample weights were calculated from carapace length frequencies using the sex specific equations in Lyons et al. (1981) to determine the average weights by fishing season, zone, period, and sex. The numbers of lobster landed commercially per zone, time period, and sex were estimated by dividing the pounds landed by stratum by the corresponding average weight from the samples. The recreational landings are reported as number harvested and were only from the summer period. We assumed that sizes of lobsters caught recreationall followed the commercial summer size distribution of the Keys irrespective of zone.

Numbers of lobsters from the commercial and recreational sectors were added together by fishing season, zone, and sex for total landings by length. Ages were assigned to lobster lengths based on sex-specific age-length keys derived from the model in Muller et al. (1997) based on tagging and recapture information that includes terms for sex, carapace length, and time period within a fishing season.

We used Integrated Catch at Age, Version 1.4 (Patterson 1998) to estimate the population size in numbers of lobsters and fishing mortality rates by fishing season and age from the catch-at-age data. In our landings data, some older ages occurred sporadically, so all lobsters age-12 and older were combined into the age-12+ group. As with previous lobster assessments, we used a natural mortality rate of 0.34 per year. Integrated Catch at Age (ICA) fits a separable virtual population analysis to a specified portion of the data, in this case the catch-at-age data since August 1993 and performs sequential population analyses on data from earlier fishing seasons. The model used three indices of abundance to identify the solution with the lowest residuals: 1) standardized commercial pounds per trip adjusted for zone, month, soak time, number of traps and trip duration expressed as days away from the dock; 2) the weight of lobsters per trap from the observer program adjusted for zone, soak time and month; and 3) the number of lobsters with carapace lengths of 68 mm to 75 mm per trap as a pre-recruit index of age-2 for females and age-1 for males. Since the standardization uses logarithms of the catch rates, the indices were normalized to the mean to focus on relative changes instead of the magnitude of the rates.

Transitional spawning potential ratios (tSPR) were calculated from age-specific total mortality rates by summing the female spawning biomass per recruit from ages 1 to 15 and comparing that biomass to the female spawning biomass with fishing mortality set to zero (spawning potential). Mature females as small as 67 mm CL have been observed but full maturity is not attained until 85 mm CL (Lyons et al. 1981). We selected a maturity schedule where 50% are mature during their first year (CL < 78 mm CL), 77% are mature in their second year (CL 78-87 mm) and 100% are mature for all older ages. Multiple spawning (Lipcius 1985) was incorporated into the SPR calculations by assuming that females less than 80 mm CL had a single brood (ages two and three and part of age-4) and larger lobsters had two broods (part of age-4 and older).

As an alternative analysis, we used a non-equilibrium, surplus-production model, ASPIC, developed by Prager (1994) to estimate the population biomass trajectory over time, landings, necessary trips, the maximum sustainable yield (MSY), the ratio of the current biomass to that at MSY, and the ratio of current fishing mortality to the fishing mortality at MSY. Because this model allows for missing data and because the NMFS's General Canvass has landings available by month and county since January 1978, we were able to extend the landings for

Monroe county data back to the 1978-79 fishing season. The number of trips for the period of 1978-79 through 1984-85 were set to missing and we approximated the number of trips in 1985-86 by applying the pounds per trip from the trips reported on trip tickets to the entire season's landings. Last year, the model only included commercial landings but because the intention of using ASPIC is to recreate the historical biomass trajectory we thought it necessary to run the model using total landings. The recreational landings were extrapolated back to the 1978-79 using commercial landings and the average weight of a spiny lobster.

RESULTS

The early commercial fishery for spiny lobsters operated primarily on the ocean side of the Florida Keys and produced landings of between 2 and 3 million pounds until 1965 (Figure 1). In 1965, the Florida Legislature changed the minimum size from one pound (approximately 80 mm CL) to 76.2 mm CL (3 inches) which allowed the fishery to expand into Florida Bay. Landings in the Keys stabilized by 1970 (test for slope equal to zero, $t = 1.42$, $d.f. = 28$, $P = 0.17$) at an average of 5.6 million pounds although landings in 1989-90 exceeded 7 million pounds. Commercial fishers during the most recent fishing season (1999-00) reported landings in the Keys of 6.3 million pounds from 22,600 trips (Table 1). With the 76-mm minimum carapace length, the average spiny lobster landed by the commercial fishery weighs slightly more than a pound such that the landings of 6.3 million pounds represent an estimated 5.2 million lobsters in the 1999-00 season.

Commercial harvesting patterns differ between the upper and lower Keys. Since the 1993-94 season, fishers from the lower Keys typically have landed about 24% more pounds of lobsters from about 30% fewer trips than do the fishers in the upper Keys. For example, in this past season fishers from the lower Keys reported higher landings (3.7 million pounds) from fewer trips (8,986 trips) than did those from the upper Keys (2.5 million pounds and 13,606 trips) (Table 1, Figure 2). In an attempt to explain the difference between zones, we looked at whether fishers in the lower Keys made longer trips, fished more traps, or soaked their traps longer. Trip duration between the two zones was tested with a general linear model that adjusted the means for fishing season, month within a season, as well as zone. On the average, fishers in the lower Keys made longer trips (adjusted mean trip duration = 1.27 days, standard error = 0.00150, n = 133,543) than did fishers in the upper Keys (adjusted mean trip duration = 1.03 days, standard error = 0.00189, n = 222,370). However, fishers in both zones fished similar numbers of traps (adjusted mean number of traps in upper Keys = 217, standard error = 0.574, n = 134,355 and adjusted mean number of traps in lower Keys = 214, standard error = 1.048, n = 25,727). The length of time that fishers soaked their traps differed in that long soak times in the upper Keys reduced the harvest of lobsters (coefficient for soak time =

-3.05 with a standard error of 0.83, *d. f. = 125147, P < 0.05*) while the length of time the traps soaked was not significant in determining the lobster harvest in the lower Keys (coefficient for soak time = 0.37 with a standard error of 0.49, *d. f. = 18343, P = 0.45*). Thus, the differences in catch rates between the two zones in the Keys is probably due to higher concentrations of spiny lobsters in the lower Keys and not just differences in fishing practices.

Estimated recreational landings from FWC surveys for the Special Sport Season in July and the first month of the regular season were about 24% of each season's commercial landings (Table 1). The recreational landings estimate during the most recent season (1.19 million lobsters) was slightly higher than the average estimated landings (1.13 million lobsters). A 1994-95 study by showed that less than 10% of the recreational landings in that season were taken after Labor day (FWC unpublished manuscript). Thus, during the 1999-00 season, a minimum of 6.4 million lobsters (5.2 million commercial and 1.2 million recreational) were landed in the Florida Keys.

The trend in overall commercial catch rates expressed in pounds per trip and adjusted with a general linear model for zone, month, soak time, number of traps, and trip duration generally has been increasing since 1990-91 to a peak in 1997-98 and a drop afterwards (Figure 3). Fewer tickets reported all of the effort data in the early years because soak time and number of traps was voluntary until 1994. The paucity of early trap data does not influence the model results because catch rates prior to 1993-94 were not used in tuning the age-structured model.

Catch rates decrease as the fishing season progresses (Figure 4 a) and differ among fishing seasons (Figure 4 b). For example, catch rates in the first two months of the 1999-00 season were the highest of the 13-year time series. As has been pointed out before, commercial landings in August are good predictors of the season landings (correlation coefficient, *r = 0.89, d. f. = 11, P < 0.05*) (Figure 5).

The ICA model fit the indices reasonably well (Figure 6 a-c) with the pre-recruit index having the greatest influence (weight = 10.00 for both sexes), followed by the observer indices (weight = 3.93 for females and weight = 10.00 for males) and finally the commercial catch rates (weight = 3.28 for females and weight = 9.79 for males). An index's weight was the inverse of the index's variance up to the program's maximum weight of 10.00. The numbers of lobsters at the beginning of the season and the instantaneous fishing mortality rates by sex, age, and fishing season are in Table 2. Although some age-1 lobsters are captured, most of the harvest is on animals age-2 through age-7. The modal age in the landings for male lobsters continues to be age-two and age-three for females. Fishing mortality rates estimated by ICA increased in 1995-96 for both sexes (Figure 7). The fishing

mortality rate for females stayed high in 1996-97 and then declined even though total landings in 1997-98 were the highest on record. The 1999-00 median fishing mortality rate for females ages 2-7 was 0.30 per year (95% confidence interval 0.21 - 0.45 per year). Beginning with the 1993-94 season, the average fishing mortality rate on fully recruited ages was 0.38 per year which is less than the common fishery benchmark $F_{0.1}$ (0.44 per year). The fishing mortality rate for males peaked with the 1995-96 season and then has remained lower. The 1999-00 average fishing mortality rate for males ages 2-7 was 0.44 per year (95% confidence interval 0.29 - 0.70 per year) and the average fishing mortality rate on fully recruited ages since 1993-94 was similar at 0.45 per year. The relationship between fishing mortality rate and the corresponding number of commercial trips shows only a general increase with more trips especially in males (Figure 8).

Output from the ICA model includes recruitment and spawning biomass trends. Recruitment, when measured by age-2 lobsters, was declining and reached a low in the 1992-93 season and then increased (Figure 9). This figure includes estimates of number of age-2 lobsters from the two previous stock assessments showing that although there have been improvements in analytical methods, the overall recruitment patterns remain consistent. The number of age-2 female lobsters reached a peak in 1997-98 and then has been lower but at higher levels than the early 1990s. The number of age-2 males generally has been higher after 1993-94 but this year's analysis indicates a leveling off at around 5.1 million lobsters. Spawning biomass of females also has tended to increase (test for slope equal zero, $t = 2.47$, $d.f. = 11$, $P < 0.05$) especially after 1993-94 whereas the males have been more variable without a significant increase (test for slope equal zero, $t = 1.15$, $d.f. = 11$, $P = 0.28$) (Figure 10). If recruitment of both males and females is compared to female spawning biomass, one clearly sees that recruitment has been higher after 1993-94 (Figure 11).

In contrast to the age-structured model, a surplus-production model requires minimal input -- landings and trips. The model estimated the biomass over the period from 1978-79 through 1999-00 and the corresponding catchability coefficient to determine the number of trips that would be necessary to produce the observed landings. The fit between the estimated number of trips and the observed was reasonable (correlation coefficient, $r = 0.87$, $d.f. = 13$, $P < 0.05$) (Figure 12). The trajectory of biomass at the beginning of the seasons estimated by this model is similar to that produced by the age-structured model (correlation coefficient, $r = 0.80$, $d.f. = 11$, $P < 0.05$) (Figure 13). The 1999-00 fishing mortality rate was similar to that producing MSY (median $F/F_{msy} = 1.02$ and 422 outcomes out of 1,000 simulation runs were less than 1.00) and the 1999-00 biomass was below the biomass at MSY (median $B/B_{msy} = 0.81$ and only 121 outcomes out of 1,000 simulation runs were greater than 1.00) (Figure 14).

Transitional spawning potential ratios (tSPR) based upon biomass calculated with the total mortality rates (natural mortality plus fishing mortality) from the ICA model varied between 23% and 29% without trend during this 13 year period (test for slope equal zero*, $t = 1.76$, d.f. = 11, $P = 0.11$*) with a value of 28% for the end of the 1999-00 fishing season (Table 2, Figure 15). When tSPR is calculated using fecundity, then the values were higher ranging between 27% and 33% with a value of 32% at the end of the 1999-00 season. The tSPR values in this assessment are higher than the tSPR values in last year's assessment because the estimated fishing mortality rates were lower in this analysis as compared to last year's. We are unable to state whether the spiny lobster stock is meeting the management objective because, there is not a quantitative management objective for spiny lobster at this time.

DISCUSSION

Overall, the commercial spiny lobster fishery in the Florida Keys has been stable since 1970. However, the landings have not been constant. Prior to the implementation of the Trap Reduction Program, seasons with landings above six million pounds occurred about every five years and then usually they were followed by seasons with low landings but that pattern changed recently and four out of the past six seasons landed more than six million pounds per year such that the 1998-99 landings were considered very low. When the fishery is looked at by zones, one sees that the most of the fluctuation in landings occurs in the upper Keys (Table 1, Figure 2). There appears to be a base level in either zone of approximately 2.2 million pounds and then depending upon the season landings in a zone be higher but a good year in the upper Keys may not correspond to a good year In the lower Keys. For example, in the 1988-89 season, the commercial landings were 3.8 million pounds but only 2.2 million pounds in the following season in the upper Keys while in the Lower Keys the landings were 3.4 million pounds in the 1988-89 season and 3.2 million in the following season. This year there were 2.5 million pounds reported from the upper Keys and 3.7 million from the lower Keys.

Last year, we speculated that perhaps high water temperatures in June-August 1998 in the Marathon area could explain the low catch rates in August 1998. Again we extracted the hourly water temperatures from Sombrero Key, Sand Key, Long Key, and Molasses and found that the temperatures in June-August 1999 were back down the monthly averages (Figure 16). In the next assessment, the catch rates in August 2000 need to be looked at closely because the average water temperature in July 2000 was even higher (87.4^{o}F) than the July 1998 temperature.

One of the questions that frequently arises is how consistent is the management advice from assessment to assessment? To address that, we plotted

recruitment and spawning biomass estimates from last year's ICA analyses together with those from this year (Figures 9 and 10). Recruitment and biomass estimates from the three analyses generally track each other. As was noted in last year's stock assessment, the inclusion of the pre-recruit index removed the spike in biomass in the 1997-98 season estimated in the 1998 assessment.

Recruitment appears to be higher after the Trap Reduction Program was implemented. Prior to reducing the number of traps, recruitment of age-2 lobsters averaged 9.1 million lobsters; however, afterwards the number of age-2 lobsters has averaged 12.6 million lobsters (Figure 11). The spawning biomass associated with the highest recruitment is not any higher than what was commonly seen before. Therefore, another explanation is that by removing traps from the fishery, fewer sub-legal lobsters are needed to bait the traps thereby increasing the young number of lobsters in the population.

The 1996 stock assessment on data through the 1995-96 fishing season concluded that the higher landings after the Trap Reduction Program was Implemented was due to higher population sizes (Muller et al. 1997). This assessment still supports that conclusion but now we believe that the population has leveled off. In other words, the spiny lobster fishery in the Florida Keys appears to developed in a stepwise fashion with a stable level of landings in the 1960s that increased to a new level after the Florida Bay region was opened up to fishing, and now the fishery appears to have reached a new plateau.

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LIST OF TABLES

Table 1. Landings summary of the Florida Keys fishery for spiny lobster by season including commercial effort (traps and trips), landings by zone, landings in number by recreational and commercial sectors.

	Statewide	Commercial										
	Commercial	Throughout Keys		Upper Keys		Lower Keys		Monroe County Total			Recreational	Total
Season	Traps*	Trips	Pounds	Trips	Pounds	Trips	Pounds	Trips	Pounds	Number	Number	Number
78-79	572,000								5,058,440			
79-80	593,000								6,949,534			
80-81	605,000								5,168,749			
81-82	622,000								4,873,130			
82-83	542,000								5,463,327			
83-84	555,000								3,729,589			
84-85	675,000								6,092,327			
85-86	564,000							33,831**	5,564,300			
86-87	576,000							26,810	4,687,363			
87-88	777,000	432	37,193	17,052	2,265,212	12,295	2,556,381	29,779	4,858,786	4,137,925	901,693	5,039,618
88-89	787,000	1,529	264,702	19,063	3,645,607	11,280	2,660,158	31,872	6,570,467	5,601,346	1,215,156	6,816,502
89-90	916,000	633	82,640	21,058	3,781,212	13,446	3,352,135	35,137	7,215,987	5,816,493	1,301,480	7,117,973
90-91	876,000	292	25,405	22,310	2,176,013	12,452	3,208,496	35,054	5,409,914	4,101,751	1,016,349	5,118,100
91-92	939,000	429	62,545	24,991	2,757,041	12,934	2,988,923	38,354	5,808,509	4,520,959	1,374,170	5,895,129
92-93	831,000	10	1,164	20,090	2,421,942	10,323	2,226,395	30,423	4,649,501	3,785,268	775,263	4,560,531
93-94	704,615	14	3,027	16,778	2,364,847	9,111	2,033,165	25,903	4,401,039	3,880,126	1,101,276	4,981,402
94-95	639,164	13	1,579	16,405	3,107,341	10,543	3,241,887	26,961	6,350,807	5,400,694	1,074,308	6,475,002
95-96	582,985	121	15,128	14,294	2,302,347	11,675	3,418,232	26,090	5,735,707	4,054,493	1,107,136	5,161,629
96-97	594,384	2	118	15,990	3,257,725	11,933	3,621,670	27,925	6,879,513	5,836,998	1,176,791	7,013,789
97-98	597,656	1	119	16,142	2,800,464	11,988	3,689,189	28,131	6,489,772	5,713,925	1,523,832	7,237,757
98-99	535,492	.	.	12,835	1,796,060	9,056	2,856,118	21,891	4,652,178	3,796,056	837,443	4,633,499
99-00	540,000	1	411	13,606	2,531,291	8,986	3,729,281	22,593	6,260,983	5,224,954	1,189,895	6,414,849

* Numbers of traps prior to 1993-94 came from National Marine Fisheries Service General Canvass. Recent numbers are the number of active trap certificates.

** Estimated from 29,017 FWC trips with landings of 4,772,530

Table 2. Number of spiny lobster harvested, estimated population size, fishing mortality rates, average fishing mortality rates for ages 2-7 by fishing season, and transitional spawning potential ratios. Natural mortality rate: 0.34 per year. Separable fit using 93-94 through 99-00 only.

Females

Number Harvested

	Fishing Season												
Age (yr)	87-88	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00
1	135,930	168,108	154,543	102,971	135,094	100,955	136,307	160,441	98,714	177,880	199,457	107,198	145,599
2	771,601	961,643	965,697	649,020	770,891	619,557	803,559	951,672	614,340	1,087,885	1,167,804	669,397	888,490
3	806,955	1,046,716	1,111,029	774,779	858,753	705,333	814,144	1,013,450	685,856	1,152,259	1,156,793	734,652	953,710
4	433,571	574,622	651,141	477,409	509,021	391,328	408,317	555,358	430,180	612,829	577,771	401,698	523,134
5	188,083	250,546	300,626	231,689	252,714	171,794	164,441	243,460	226,351	262,653	235,060	174,272	231,324
6	78,656	103,278	129,282	104,882	119,101	71,878	63,073	99,784	117,343	108,230	91,879	71,962	97,861
7	33,566	41,584	55,497	46,906	57,141	30,527	24,292	40,104	62,988	45,584	36,148	29,737	41,740
8	14,634	16,220	23,463	21,025	24,700	13,270	9,608	15,794	32,284	19,717	14,372	12,491	17,685
9	6,739	6,450	11,222	19,070	10,857	5,908	4,267	6,554	17,410	10,594	6,117	6,279	8,012
10	3,892	2,665	6,833	22,504	5,256	3,914	2,483	3,227	10,286	8,146	3,110	5,370	5,345
11	2,368	1,090	4,024	18,141	2,635	3,344	1,583	1,668	5,524	5,938	1,632	4,720	4,090
12+	4,402	722	5,574	41,078	2,120	8,103	2,679	2,330	6,984	7,136	1,387	9,937	7,338
Ages 2 - 7	2,327,065	2,994,608	3,236,735	2,305,710	2,592,321	2,003,687	2,287,433	2,919,622	2,169,341	3,289,157	3,279,828	2,094,208	2,753,944
Total	2,480,396	3,173,644	3,418,932	2,509,474	2,748,283	2,125,912	2,434,752	3,093,842	2,308,259	3,498,851	3,491,531	2,227,713	2,924,328

Beginning Population size

	Fishing Season													
Age (yr)	87-88	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01
1	8,861,111	8,162,590	7,607,853	7,523,801	7,775,336	8,126,643	9,348,320	8,701,758	9,850,862	10,881,426	8,376,429	8,804,349	9,457,693	8,725,447
2	6,467,470	6,193,006	5,668,841	5,285,376	5,268,802	5,420,893	5,699,575	6,556,251	6,083,768	6,856,033	7,571,533	5,858,734	6,171,043	6,609,521
3	3,632,325	3,958,261	3,605,155	3,229,177	3,219,438	3,106,356	3,340,355	3,527,609	3,939,716	3,502,498	3,938,453	4,567,601	3,605,586	3,693,664
4	1,658,155	1,913,568	1,947,614	1,644,784	1,653,915	1,578,004	1,623,929	1,809,836	1,804,202	1,853,333	1,640,617	2,029,734	2,447,493	1,829,960
5	745,363	819,904	885,362	847,048	774,496	755,122	797,760	854,958	894,005	812,547	830,734	817,269	1,055,595	1,198,759
6	404,197	374,154	375,805	381,295	410,466	341,905	394,483	425,427	428,943	410,549	371,455	420,162	430,749	525,313
7	204,483	222,135	180,540	160,484	184,287	193,312	183,487	219,118	224,241	209,548	199,784	197,153	231,042	225,465
8	213,128	117,532	123,437	82,484	75,303	83,794	112,111	106,879	122,340	117,741	109,681	112,172	113,909	128,272
9	48,371	139,441	70,105	68,298	41,231	33,138	48,565	68,602	63,344	69,225	66,465	65,280	68,219	67,223
10	13,618	28,799	93,843	40,531	32,778	20,325	18,659	30,517	41,987	37,316	40,701	40,821	40,813	41,606
11	13,452	6,462	18,268	61,072	10,475	18,943	11,204	11,486	18,218	23,975	21,260	24,397	24,981	24,266
12+	25,007	4,281	25,305	138,290	8,428	45,902	18,997	13,879	34,042	34,471	8,437	67,940	42,815	38,561
Ages 2 - 7	13,111,993	13,481,028	12,663,317	11,548,164	11,511,404	11,395,592	12,039,589	13,393,199	13,374,875	13,644,508	14,552,576	**********	13,941,508	14,082,682
Total	22,286,680	21,940,133	20,602,128	19,462,640	19,454,955	19,724,337	21,597,445	22,326,320	23,505,668	24,808,662	23,175,549	**********	23,689,938	23,108,057

Fishing Mortality Rates

	Fishing Season													
Age (yr)	87-88	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	Selectivity
1	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.049
2	0.15	0.20	0.22	0.16	0.19	0.14	0.14	0.17	0.21	0.21	0.17	0.15	0.17	0.464
3	0.30	0.37	0.44	0.33	0.37	0.31	0.27	0.33	0.41	0.42	0.32	0.28	0.34	0.905
4	**0.36**	**0.43**	**0.49**	**0.41**	**0.44**	**0.34**	**0.30**	**0.37**	**0.46**	**0.46**	**0.36**	**0.31**	**0.37**	**1.000**
5	0.35	0.44	0.50	0.38	0.48	0.31	0.29	0.35	0.44	0.44	0.34	0.30	0.36	0.957
6	0.26	0.39	0.51	0.39	0.41	0.28	0.25	0.30	0.38	0.38	0.29	0.26	0.31	0.822
7	0.21	0.25	0.44	0.42	0.45	0.20	0.20	0.24	0.30	0.31	0.24	0.21	0.25	0.665
8	0.08	0.18	0.25	0.35	0.48	0.21	0.15	0.18	0.23	0.23	0.18	0.16	0.19	0.501
9	0.18	0.06	0.21	0.39	0.37	0.23	0.12	0.15	0.19	0.19	0.15	0.13	0.15	0.413
10	0.41	0.12	0.09	1.01	0.21	0.26	0.15	0.18	0.22	0.22	0.17	0.15	0.18	0.481
11	0.23	0.22	0.30	0.43	0.35	0.23	0.18	0.22	0.27	0.28	0.21	0.19	0.22	0.600
12+	0.23	0.22	0.30	0.43	0.35	0.23	0.18	0.22	0.27	0.28	0.21	0.19	0.22	0.600
Average Ages 2-7	0.27	0.35	0.44	0.35	0.39	0.27	0.24	0.29	0.37	0.37	0.29	0.25	0.30	

Transitional Spawning Potential Ratios (SPR)

	Fishing Season												
	87-88	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00
Biomass	26%	27%	25%	24%	23%	24%	27%	29%	28%	26%	25%	27%	28%
Fecundity	29%	30%	28%	27%	27%	28%	31%	33%	31%	29%	29%	30%	32%

Table 2 (Continued). Number of spiny lobster harvested, estimated population size, fishing mortality rates, average fishing mortality rates for ages 2-7 by fishing season, and transitional spawning potential ratios. Natural mortality rate: 0.34 per year. Separable fit using 93-94 through 99-00 only.

Males

Number Harvested

	Fishing Season												
Age (yr)	87-88	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00
1	475,980	645,130	544,271	376,152	430,058	385,354	503,645	587,927	328,136	619,729	729,049	378,804	598,949
2	1,098,352	1,572,221	1,440,849	981,450	1,167,715	993,881	1,128,498	1,397,557	862,529	1,474,698	1,648,219	967,783	1,445,130
3	599,151	882,535	939,810	639,492	783,674	607,075	574,397	806,989	708,707	832,201	846,171	592,743	829,140
4	235,604	342,622	429,624	303,642	387,764	257,579	211,542	344,009	441,889	340,815	319,365	257,562	350,302
5	89,803	121,984	184,606	141,872	194,830	102,772	76,151	140,977	233,134	135,096	121,532	106,260	145,333
6	35,065	44,313	79,718	69,466	98,848	42,386	28,696	58,489	122,965	55,846	48,476	45,603	62,942
7	14,162	16,766	35,291	34,909	46,304	18,950	11,402	24,434	64,744	24,351	19,708	20,560	27,842
8	5,924	6,585	16,583	20,802	20,893	9,814	5,090	10,982	39,293	11,695	8,098	10,894	13,185
9	2,512	4,579	9,098	17,382	9,137	8,624	2,458	5,331	24,146	8,342	3,309	7,105	7,228
10	1,083	2,009	4,391	8,860	3,783	4,367	1,124	2,411	12,511	4,031	1,369	3,569	3,375
11	464	786	1,994	4,057	1,535	1,947	508	1,066	6,127	1,760	562	1,669	1,496
12+	1,127	3,329	12,802	10,547	2,298	1,879	3,131	989	9,196	6,355	369	13,246	5,588
Ages 2 - 7	2,078,062	2,987,026	3,126,482	2,191,633	2,700,028	2,032,457	2,035,775	2,783,438	2,473,262	2,874,703	3,011,568	2,001,404	2,873,874
Total	2,559,229	3,642,859	3,699,038	2,608,631	3,146,840	2,434,628	2,546,642	3,381,162	2,853,379	3,514,919	3,746,226	2,405,798	3,490,511

Beginning Population size

	Fishing Season													
Age (yr)	87-88	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01
1	8,097,400	7,348,230	6,403,201	6,272,579	6,177,900	6,506,182	8,014,658	8,003,435	8,996,258	9,125,521	6,848,798	7,366,182	8,304,091	7,692,038
2	5,120,733	5,364,658	4,690,256	4,101,988	4,149,465	4,037,034	4,308,018	5,433,493	5,325,837	5,609,452	5,953,384	4,550,608	4,849,779	5,408,977
3	2,353,672	2,730,070	2,513,760	2,143,584	2,103,207	1,983,940	2,046,892	2,502,261	2,920,038	2,181,422	2,775,253	3,179,310	2,339,054	2,383,702
4	971,022	1,177,188	1,211,946	1,012,616	995,219	849,373	908,672	1,114,892	1,230,422	1,004,273	961,995	1,353,371	1,474,349	1,022,632
5	414,360	495,176	553,548	507,236	468,868	388,225	390,924	496,569	550,728	426,989	445,504	471,319	630,930	648,474
6	210,711	220,148	251,006	241,122	243,233	173,115	190,931	216,759	250,270	198,820	194,407	222,800	224,899	284,952
7	90,933	120,716	119,770	112,588	113,966	91,595	87,966	107,380	111,410	93,903	92,849	99,193	108,756	104,232
8	53,209	52,900	71,916	55,966	51,193	42,925	49,408	50,409	56,640	43,988	45,349	48,647	49,896	52,156
9	18,014	32,918	32,149	37,387	22,643	19,207	22,385	28,509	26,845	22,787	21,508	23,993	24,742	24,231
10	5,821	10,723	19,605	15,329	12,326	8,579	6,576	12,565	14,614	10,020	10,605	10,944	11,676	11,427
11	2,220	3,240	5,958	10,299	3,690	5,636	2,528	3,653	6,348	5,301	4,576	5,317	5,237	5,290
12+	5,391	13,723	38,249	26,774	5,525	5,439	15,614	3,735	20,569	19,443	1,368	44,302	16,856	9,659
Ages 2 - 7	9,161,431	10,107,956	9,340,286	8,119,134	8,073,958	7,523,282	7,933,403	9,871,354	10,388,705	9,514,859	10,423,392	9,876,601	9,627,767	9,852,969
Total	17,343,486	17,569,690	15,911,364	14,537,468	14,347,235	14,111,250	16,044,572	17,973,660	19,509,979	18,741,919	17,355,596	17,375,986	18,040,265	**********

Fishing Mortality Rates

	Fishing Season													
Age (yr)	87-88	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	Selectivity
1	0.07	0.11	0.11	0.07	0.09	0.07	0.05	0.07	0.13	0.09	0.07	0.08	0.09	0.182
2	0.29	0.42	0.44	0.33	0.40	0.34	0.20	0.28	0.55	0.36	0.29	0.33	0.37	0.760
3	**0.35**	**0.47**	**0.57**	**0.43**	**0.57**	**0.44**	**0.27**	**0.37**	**0.73**	**0.48**	**0.38**	**0.43**	**0.49**	**1.000**
4	0.33	0.41	0.53	0.43	0.60	0.44	0.26	0.37	0.72	0.47	0.37	0.42	0.48	0.988
5	0.29	0.34	0.49	0.39	0.66	0.37	0.25	0.35	0.68	0.45	0.35	0.40	0.45	0.933
6	0.22	0.27	0.46	0.41	0.64	0.34	0.24	0.33	0.64	0.42	0.33	0.38	0.43	0.880
7	0.20	0.18	0.42	0.45	0.64	0.28	0.22	0.30	0.59	0.39	0.31	0.35	0.39	0.810
8	0.14	0.16	0.31	0.56	0.64	0.31	0.21	0.29	0.57	0.38	0.30	0.34	0.38	0.784
9	0.18	0.18	0.40	0.77	0.63	0.73	0.24	0.33	0.65	0.42	0.34	0.38	0.43	0.888
10	0.25	0.25	0.30	1.08	0.44	0.88	0.25	0.34	0.67	0.44	0.35	0.40	0.45	0.927
11	0.28	0.33	0.49	0.61	0.66	0.51	0.27	0.37	0.73	0.48	0.38	0.43	0.49	1.000
12+	0.28	0.33	0.49	0.61	0.66	0.51	0.27	0.37	0.73	0.48	0.38	0.43	0.49	1.000
Average Ages 2-7	0.28	0.35	0.49	0.41	0.58	0.37	0.24	0.33	0.65	0.43	0.34	0.38	0.44	

LIST OF FIGURES

13. Comparison of the relative lobster biomass at the beginning of the season estimated by ASPIC and that estimated from the ICA model for both sexes.

14. Distributions of the ratios of 1998-99 biomass (a) and 1998-99 fishing mortality rates (b) to those at MSY from 1 000 simulation runs.

15. Transitional spawning potential ratios by fishing season calculated using biomasses (ellipses) and fecundity (triangles).

16. Monthly average water temperatures in the Upper Keys (Molasses, Sombrero, Long Key stations) for 1988-99 average temperatures and for 1999 monthly averages.

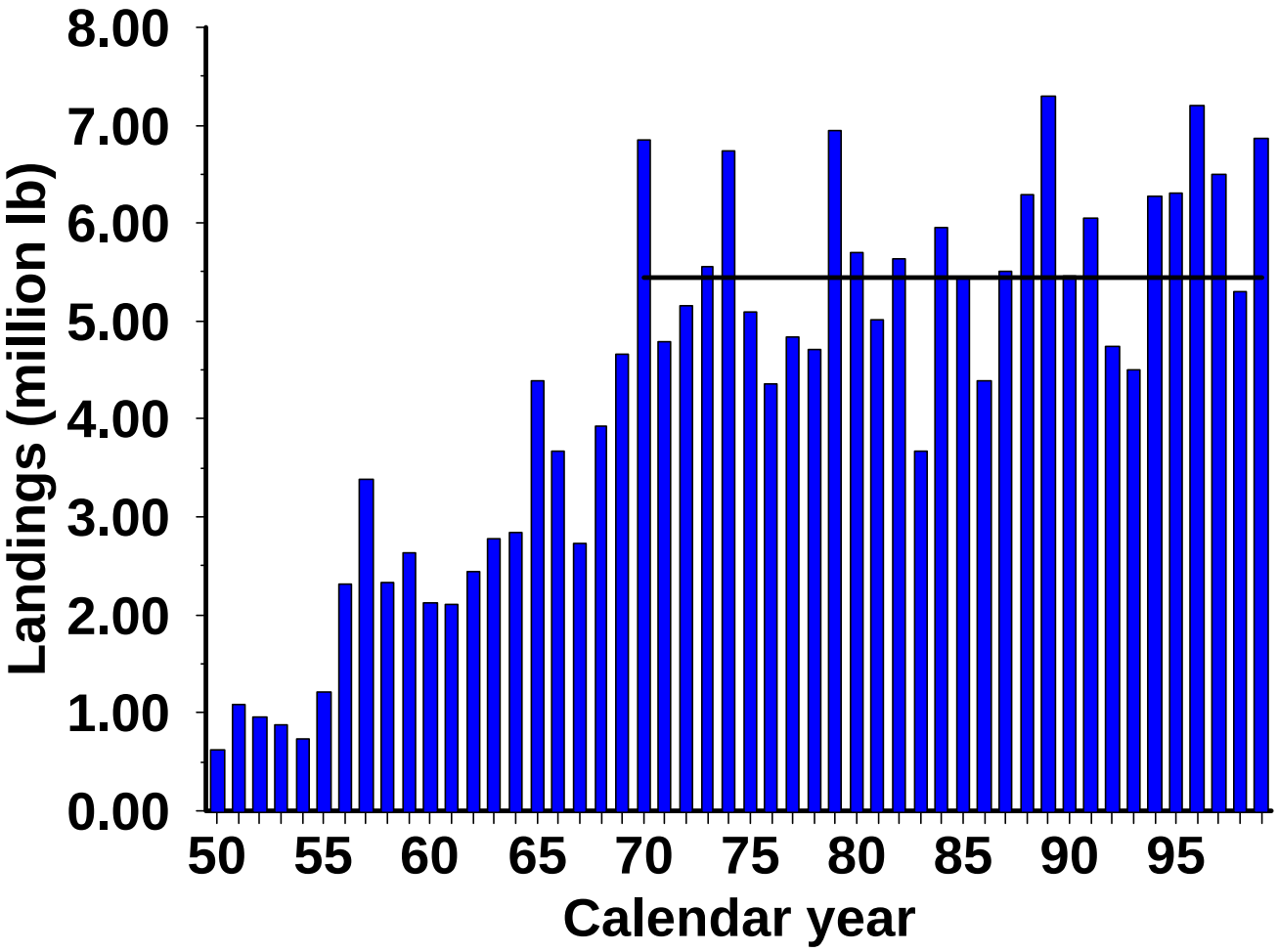


Figure 1. Historical spiny lobster landings from the west coast of of Florida by calendar year and the 1970-92 average (pre Trap Reduction Program).

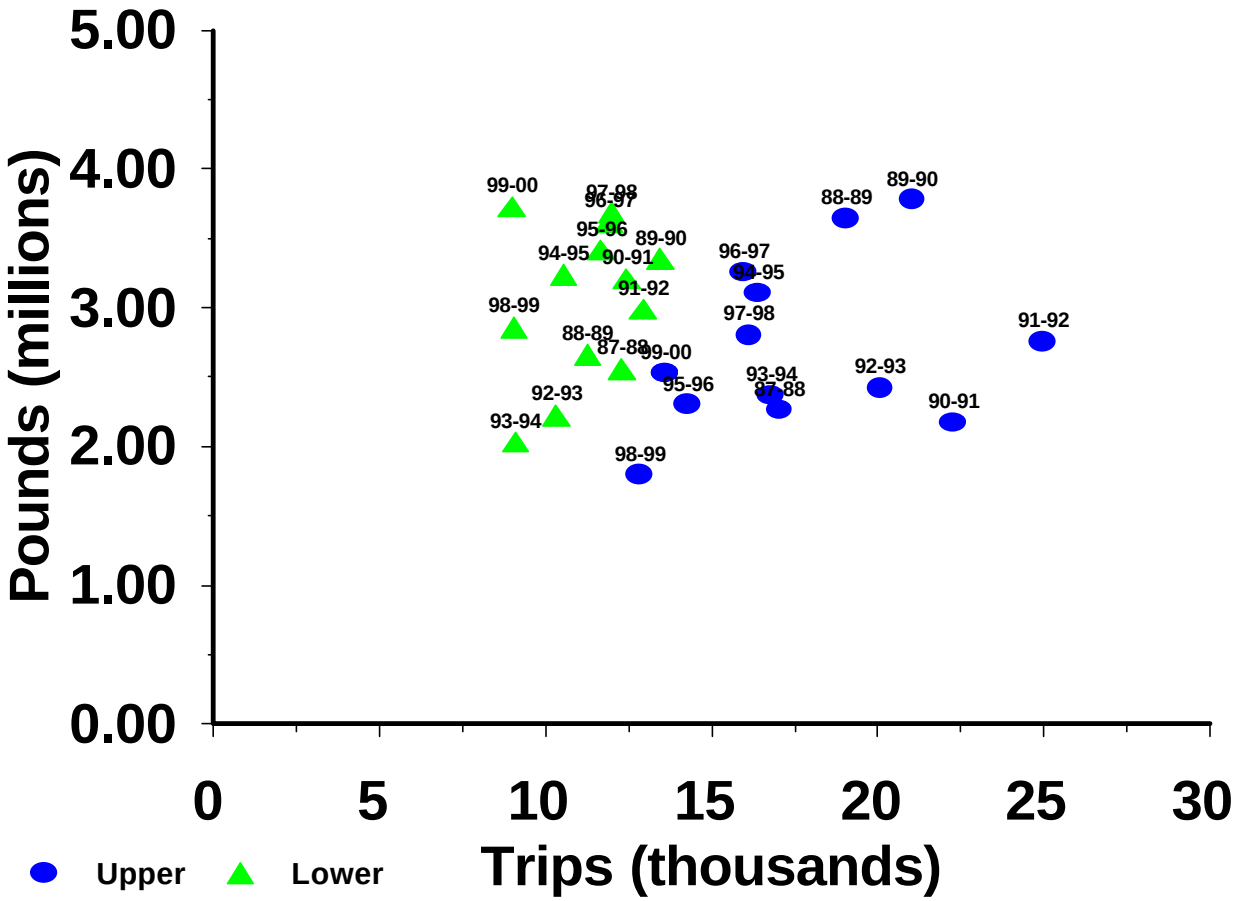


Figure 2. Landings and effort by zone and fishing season.

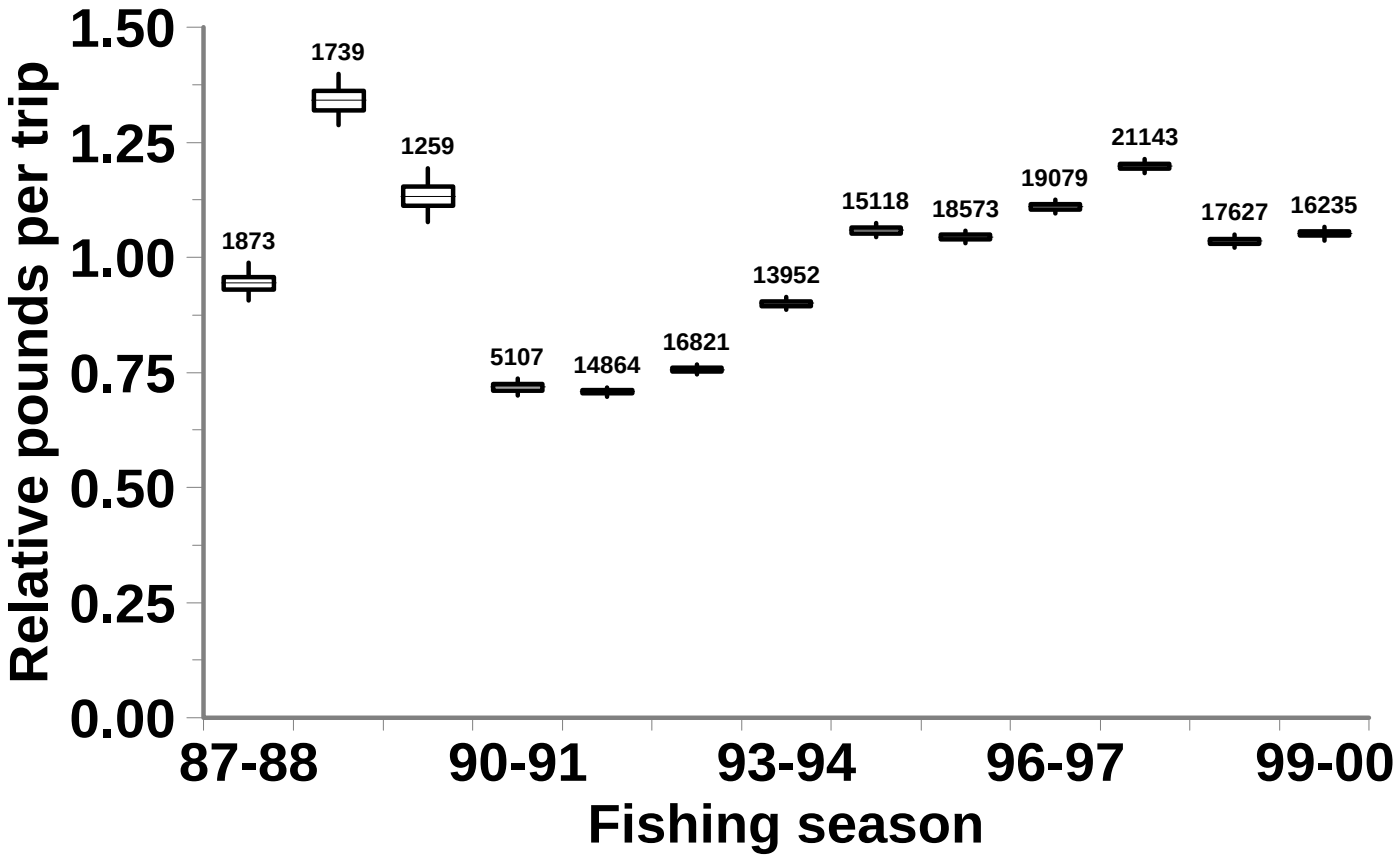
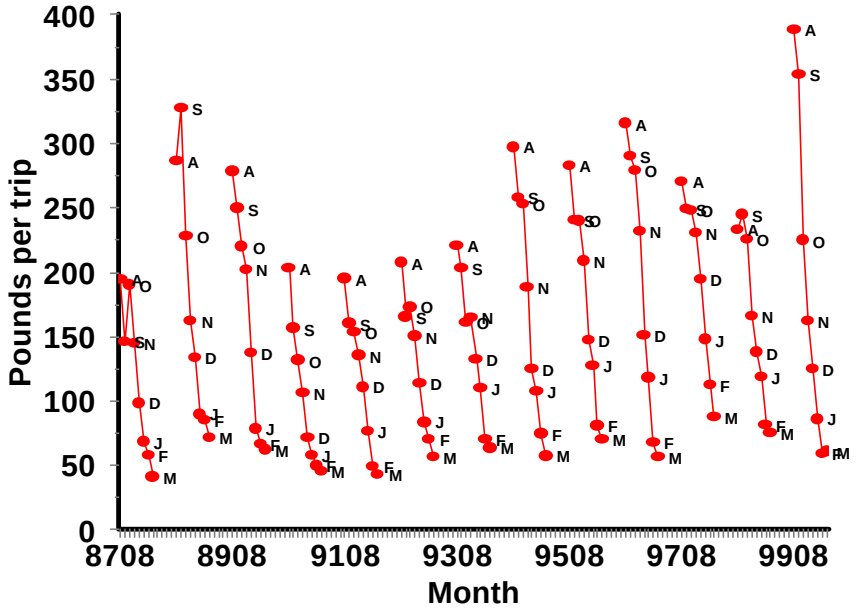


Figure 3. Distribution of standardized commercial catch rates in relative pounds per trip by fishing season from 1 000 simulation runs. Vertical line – 95% confidence interval, the box – interquartile range, and horizontal line – median.

a.



b.

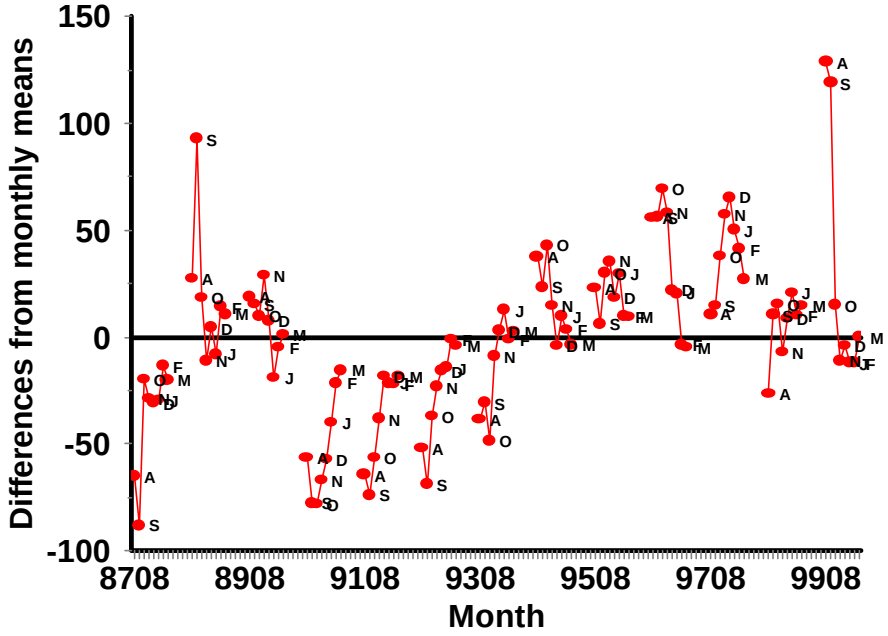


Figure 4. Seasonal availability. Standardized pounds per trip adjusted for soak time, number of traps, and trip duration. a) Monthly pounds per trip and b) seasonally adjusted monthly pounds per trip calculated by subtracting the monthly averages.

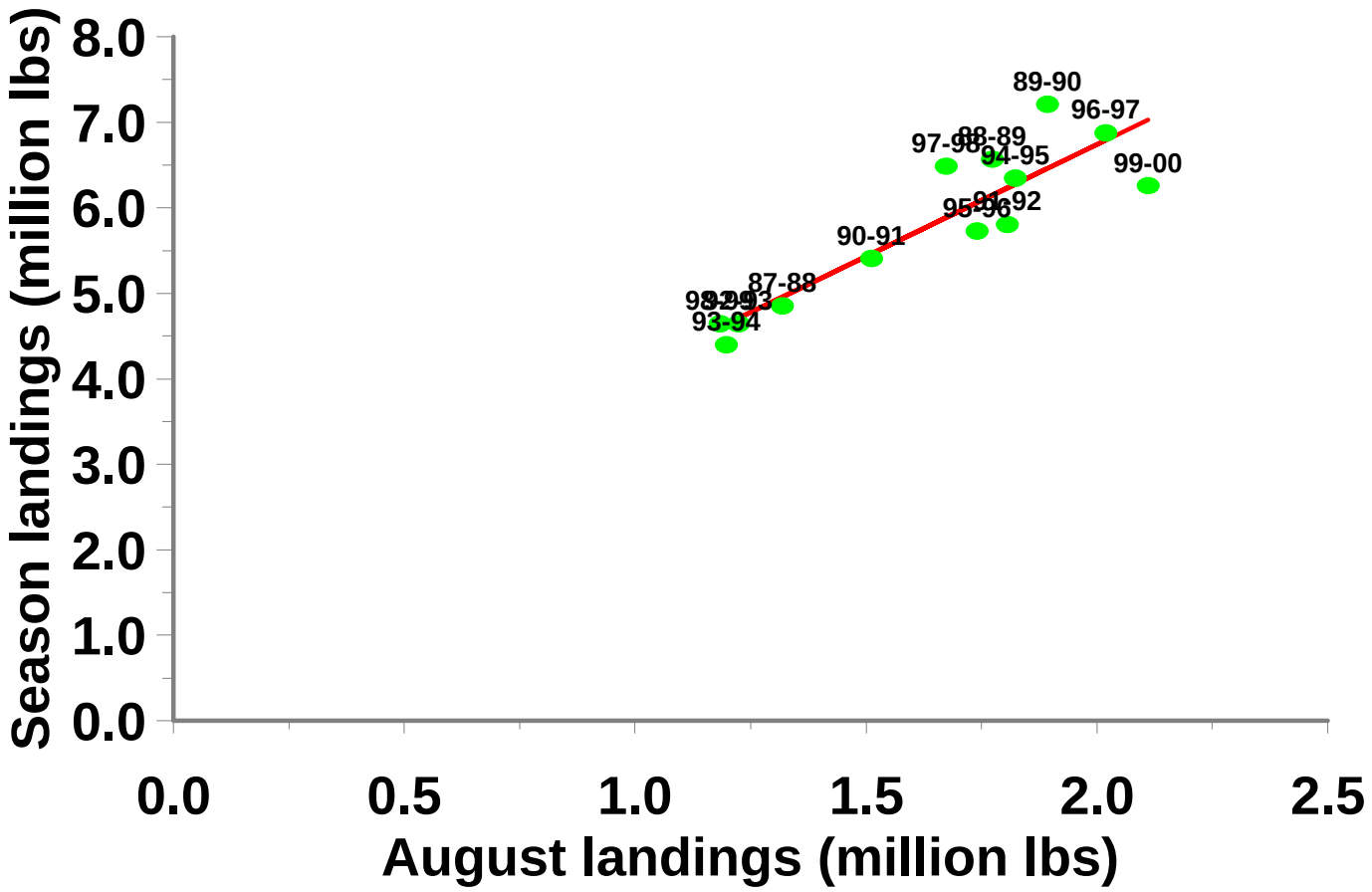
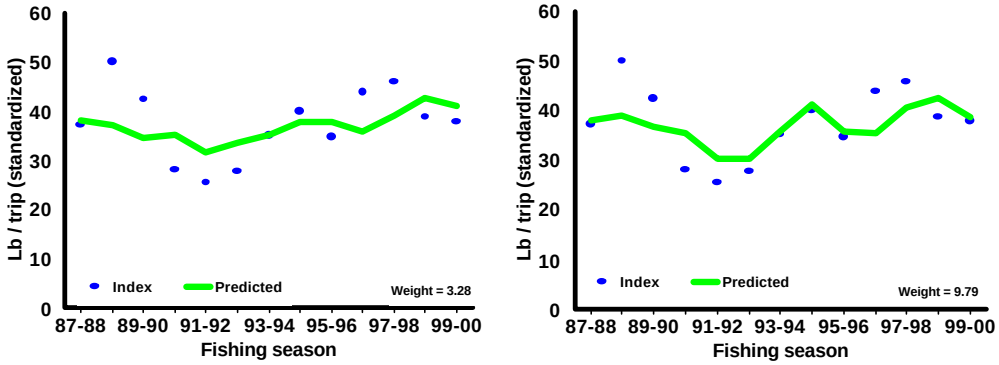


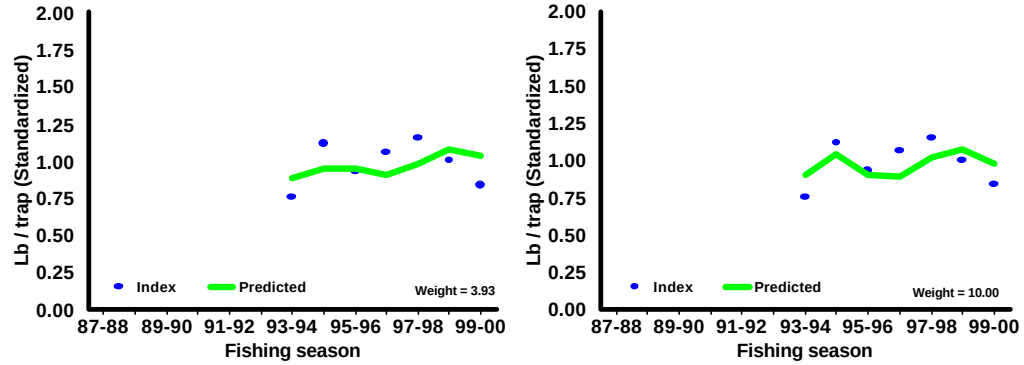
Figure 5. The relationship between season landings and August landings (R-squared = 0.80, d.f. = 11).

Females Males

a. Commercial indices



b. Observer catch rate indices



c. Pre-recruit indices

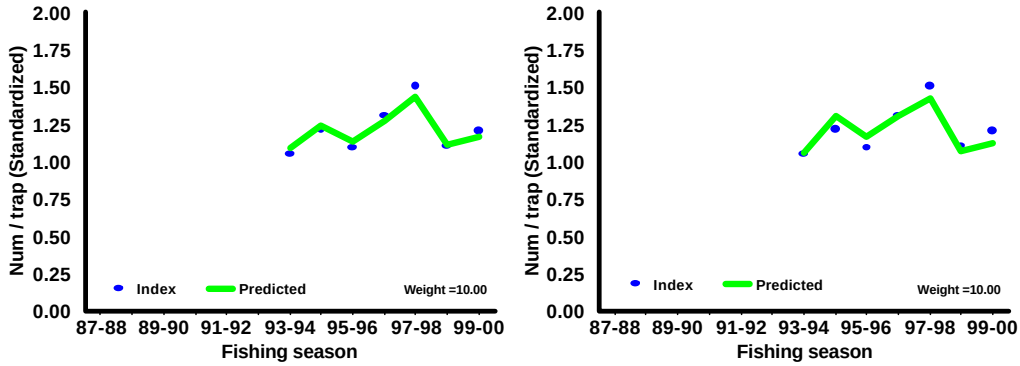
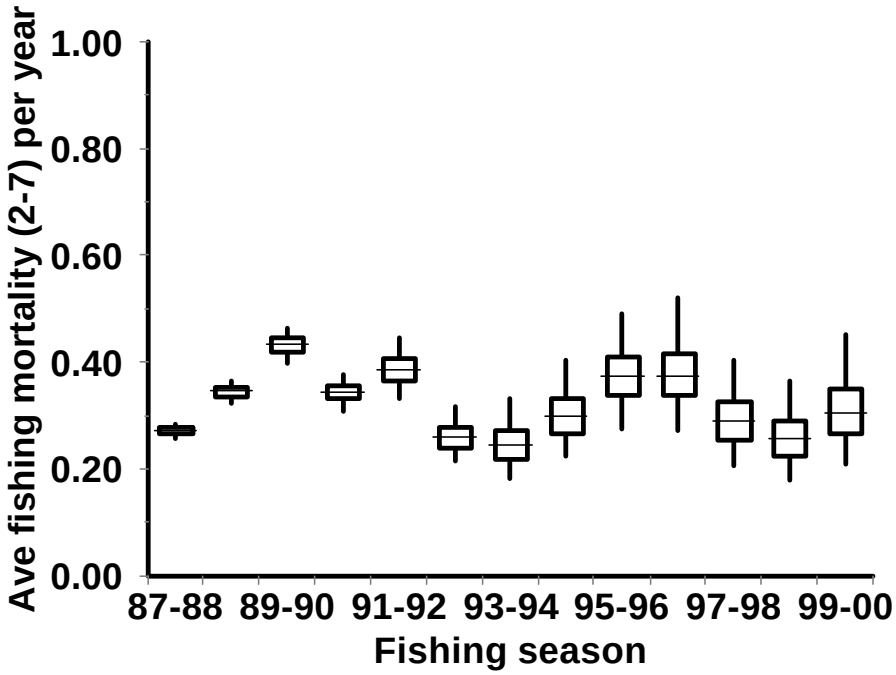


Figure 6. Observed and predicted values of the indices used to tune the separable virtual population analysis. a) Pounds per commercial trip, b) Observed pounds per trap, and c) number of pre-recruits (females age-2 and males age-1) per trap.

a. Females



b. Males

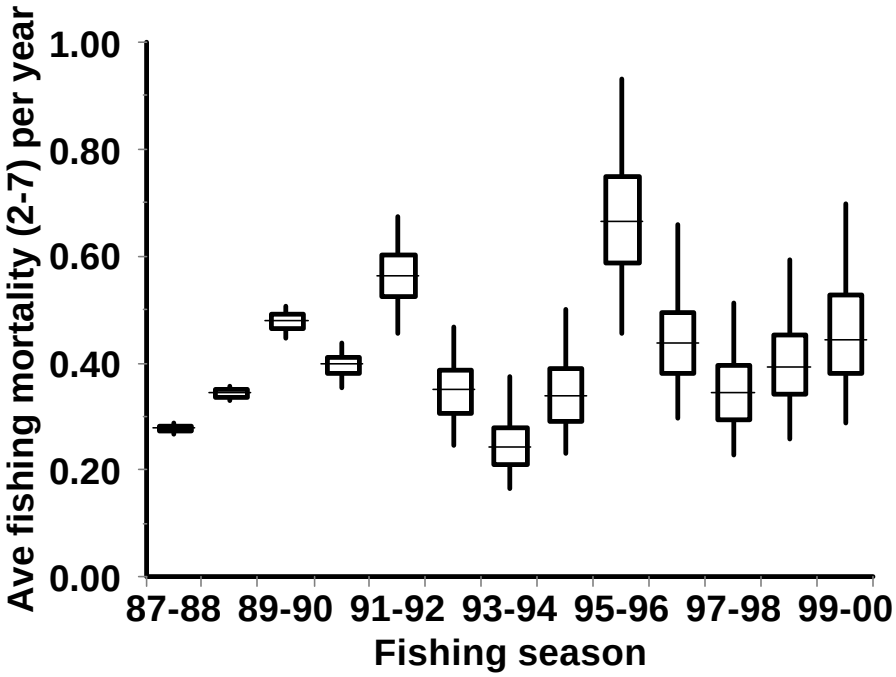
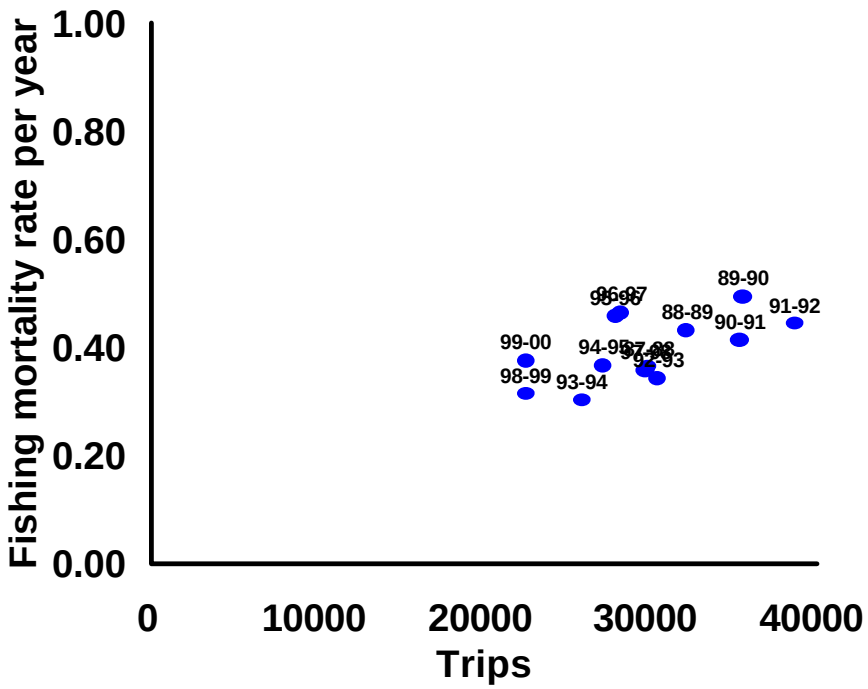


Figure 7. Distribution of average fishing mortality rates for ages 2-7 by sex. Vertical line -- 95% confidence interval, box -- inter-quartile range, and horizontal line -- median.

a. Females



b. Males

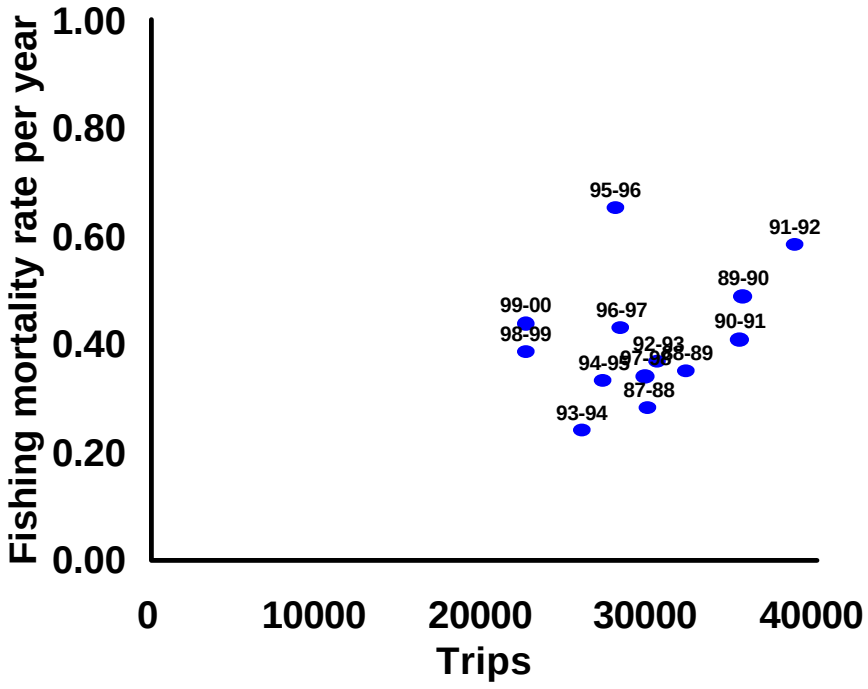
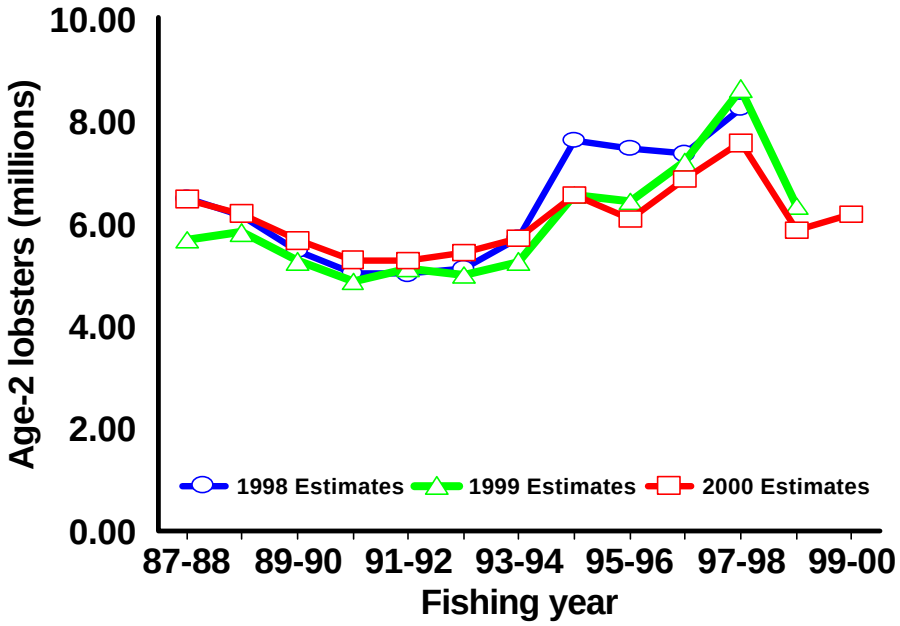


Figure 8. Relationship between fishing mortality rate and the number of commercial trips by sex.

a. Females



b. Males

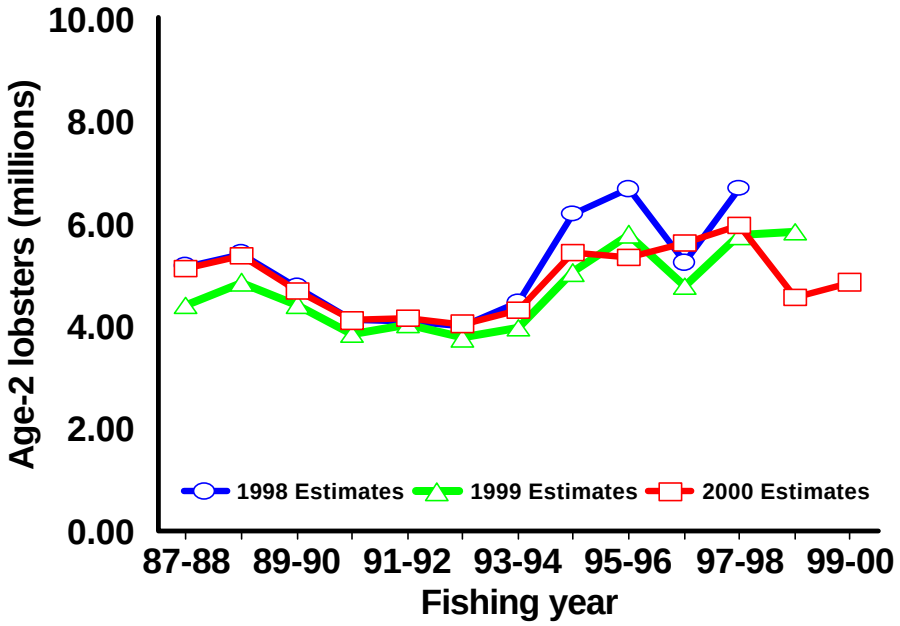
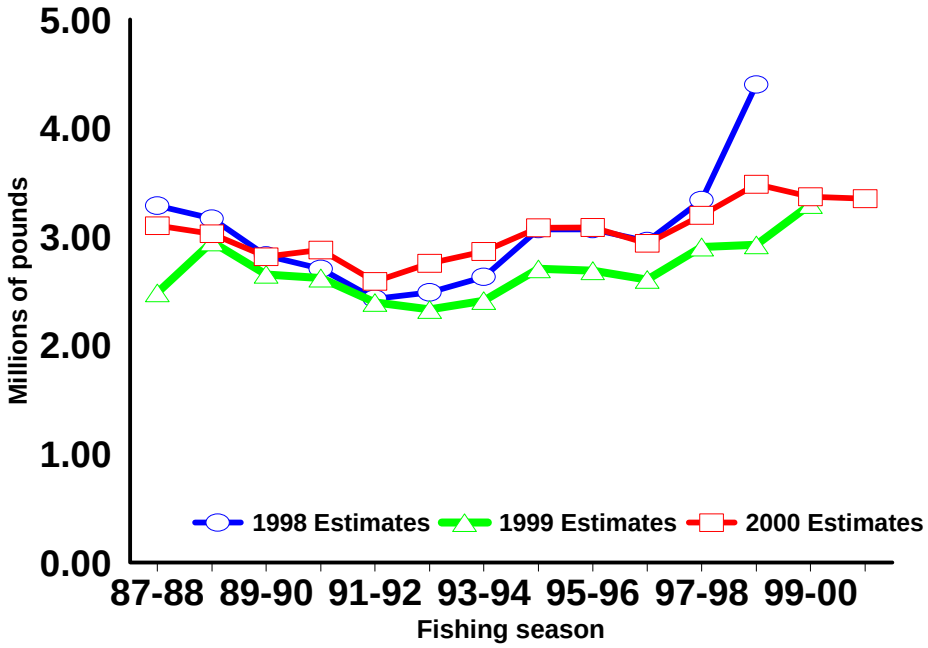


Figure 9. Comparison of recruitment (age-2) of females (a) and males (b) from the 1998, 1999 and 2000 ICA analyses.

a. Females



b. Males

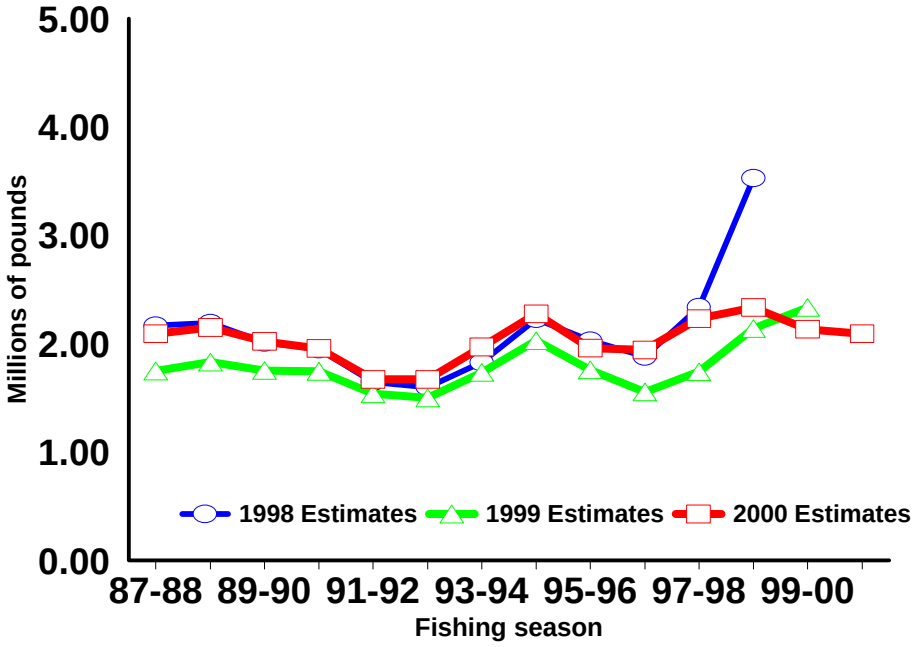


Figure 10. Comparison of spawning biomass of females (a) and males (b) from the 1998, 1999 and 2000 ICA analyses.

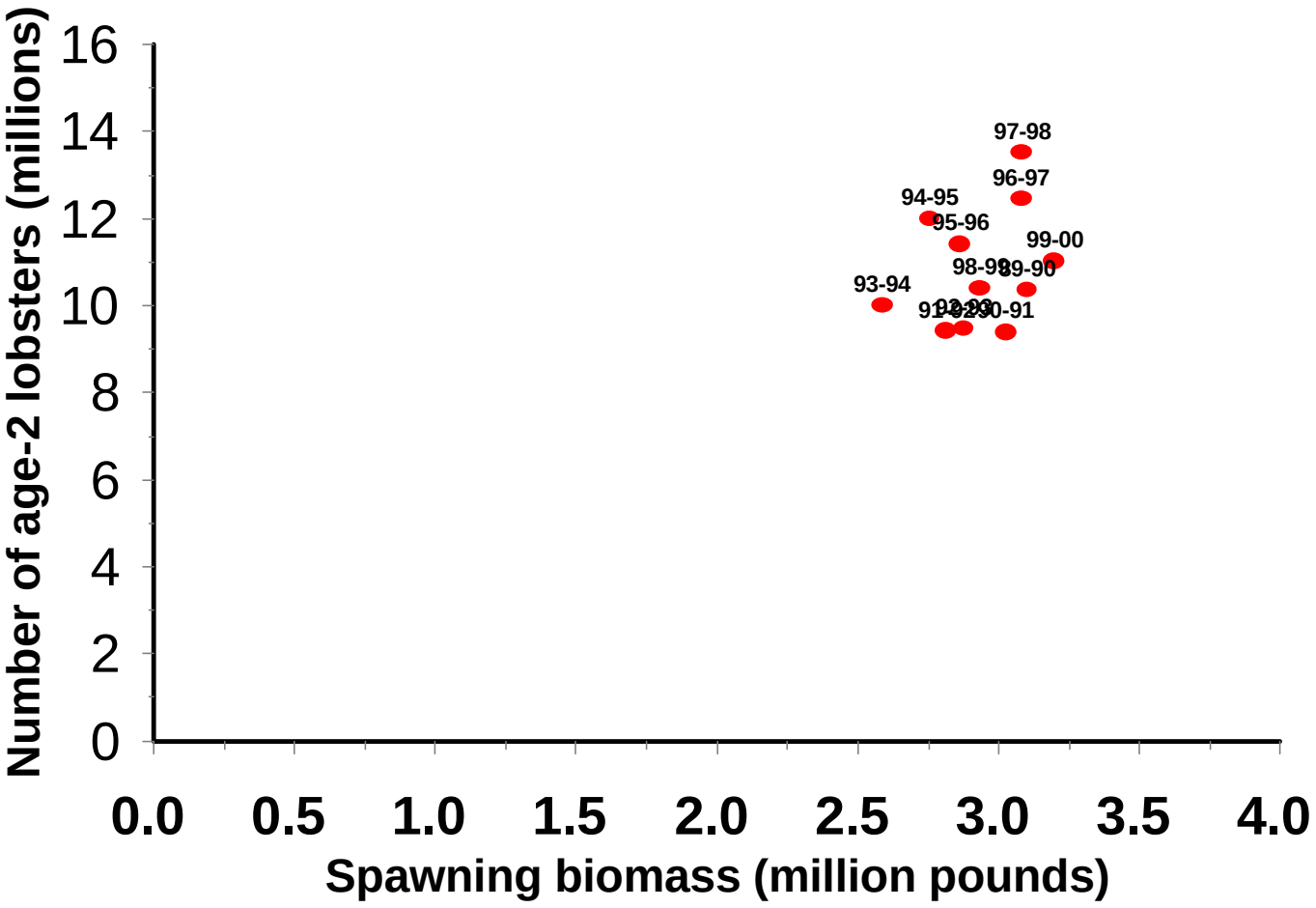


Figure 11. Recruitment of age-2 lobsters both sexes combined and the corresponding female spawning biomass two years earlier.

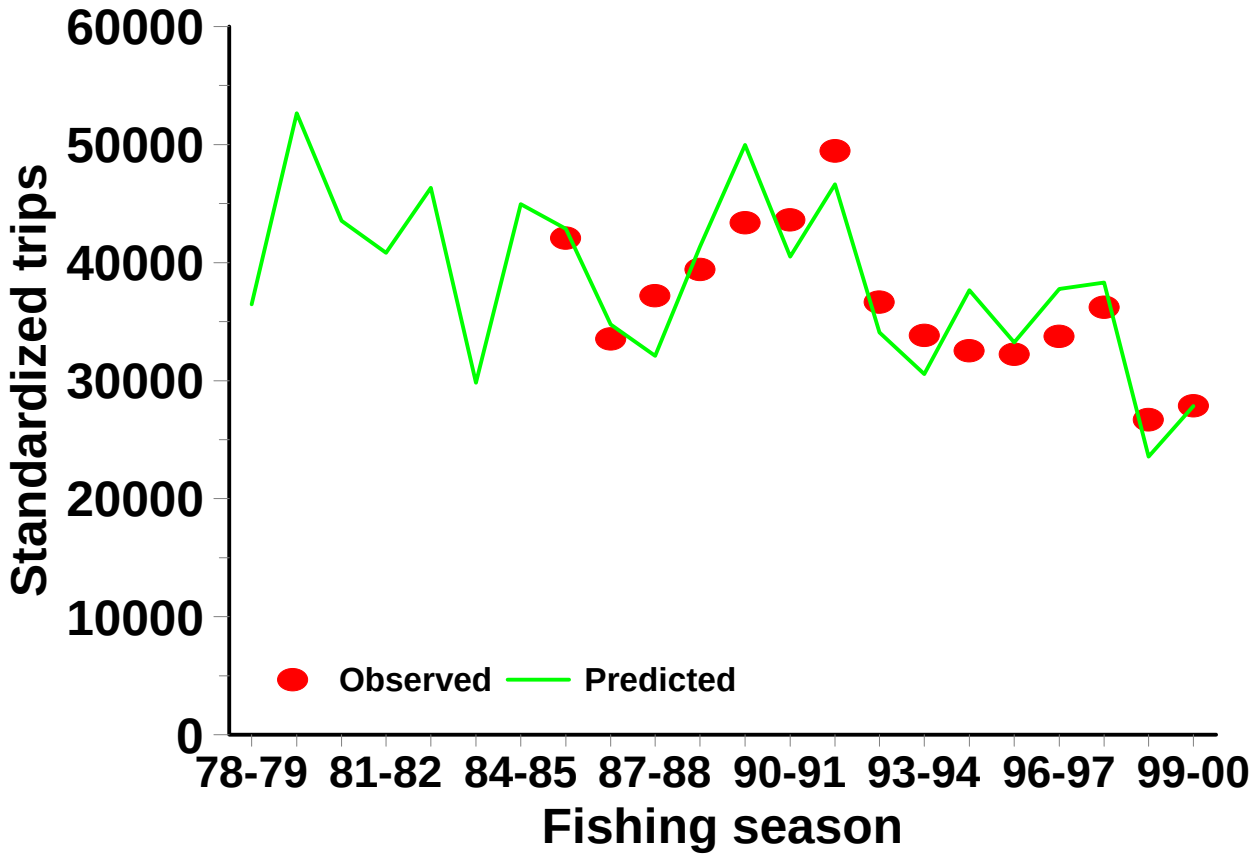


Figure 12. Predicted number of trips from ASPIC based on reported landings and observed number of lobster trips in the Florida Keys

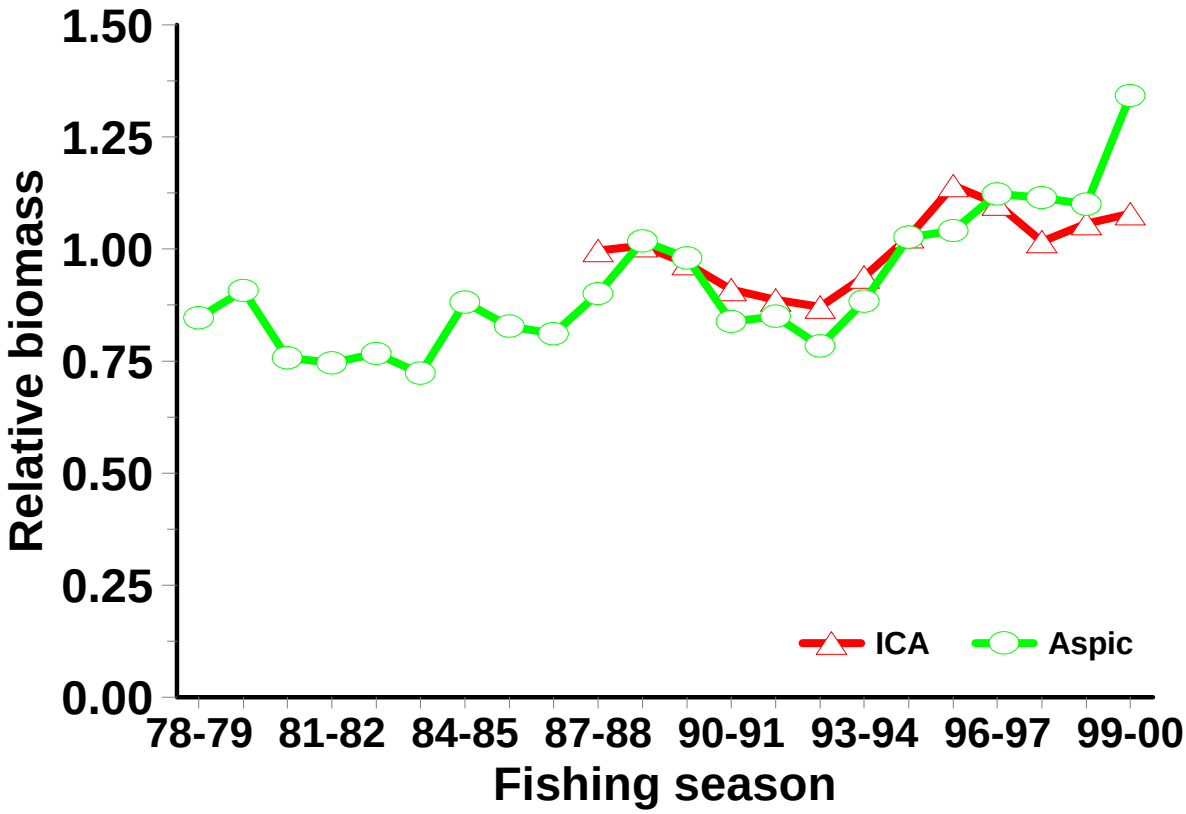
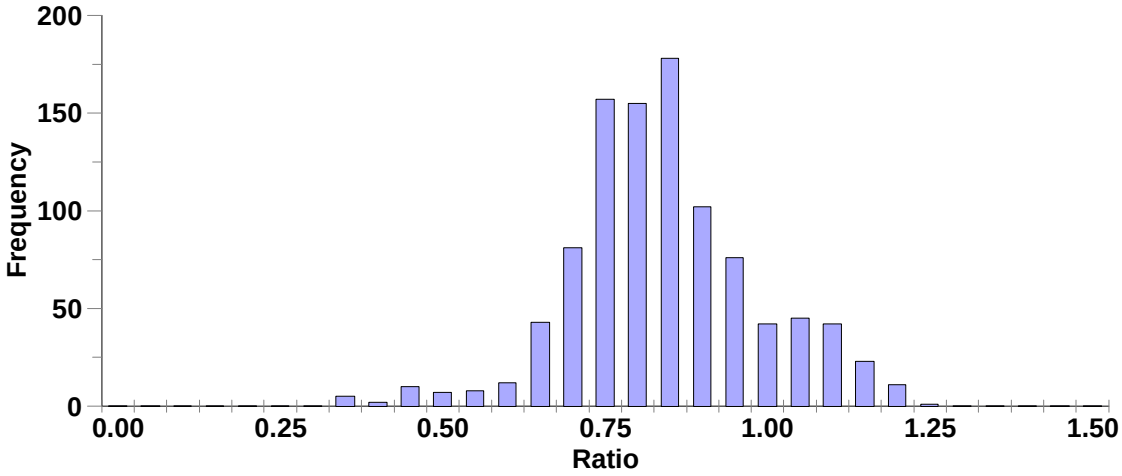


Figure 13. Comparison of the relative lobster biomass at the beginning of the season estimated by ASPIC to that estimated from the ICA model for both sexes.

a. Ratio of estimated biomass in 2000 to biomass at MSY.



b. Ratio of fishing mortality in 2000 to fishing mortality at MSY.

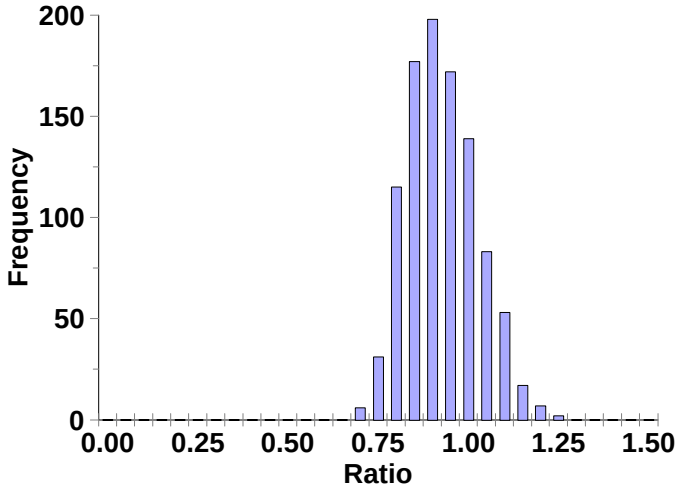


Figure 14. Distributions of the ratios of biomass and fishing mortality to those at MSY from 1 000 simulation runs.

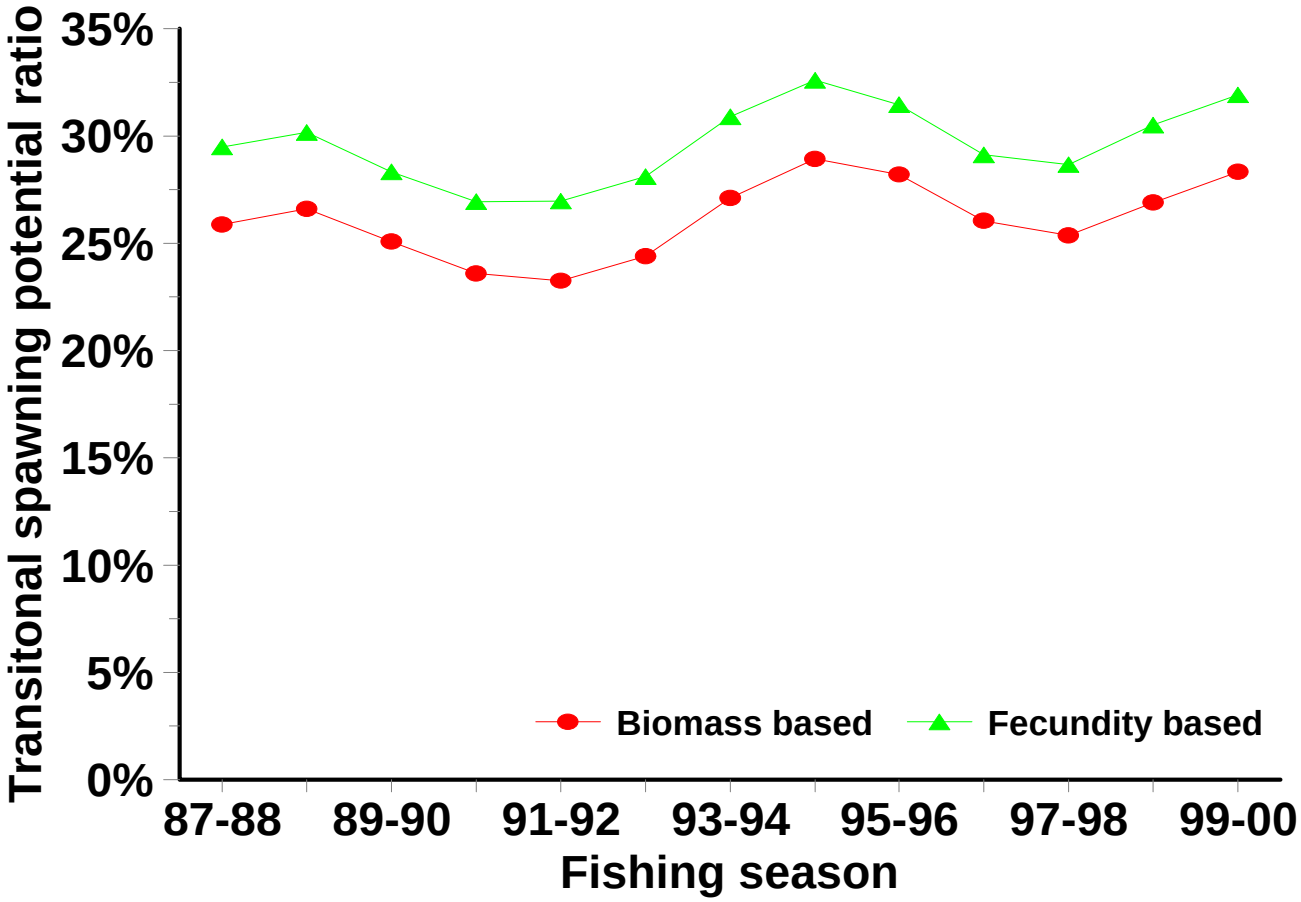


Figure 15. Transitional spawning potential ratios by fishing season calculated using biomass (ellipses) and fecundity (triangles).

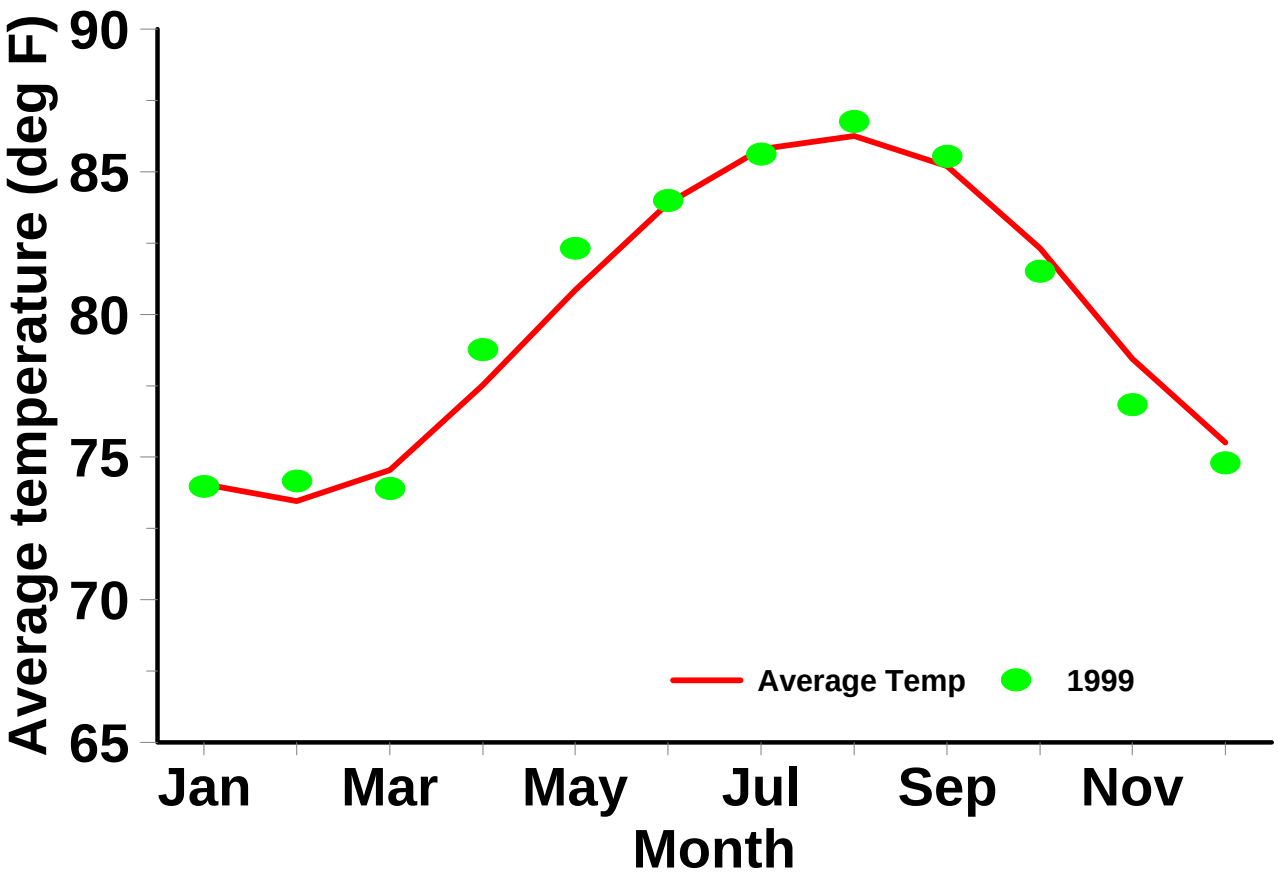


Figure 16. Monthly average water temperatures in the Upper Keys (Molasses, Sombrero, and Long Key stations) for 1988-99 average temperatures and for 1999 monthly averages.